/

UNIVERSITY OF CAMBRIDGE
DEPARTMENT OF HISTORY AND PHILOSOPHY OF SCIENCE

FREE SCHOOL LANE
CAMBRIDGE CB2 3RH
TEL: CAMBRIDGE (0223) 334540

FROM HEAD OF DEPARTMENT

PROFESSOR M. L. G. REDHEAD

30.10.88

Dear Ms Matthews,

I enclose the corrected proofs of my Inaugural Lecture, together with the typescript.

Notice that I have re-inserted the deletion made by the subeditor on p. 3, which spoiled my joke about ad hocness! The printer's mistakes are marked in red, my own corrections in black.

Do you think we should include somewhere the date on which the lecture was given, viz. 17th November 1987?

Thanking you for your attention.

Yours sincerely
Michael Redhead

DIRECT LINE: CAMBRIDGE (0223) 334556

CAMBRIDGE UNIVERSITY PRESS

The right of the University of Cambridge to print and sell all manner of books was granted by Henry VIII in Royal Letters Patent of 20 July 1534

STYLE CHECKLIST

English-style books

NB: This is designed to summarise how the subeditor has marked up the typescript, and is for the typesetter and the proofreader to refer to when setting/proofreading the book. Any specific instructions should be headed 'Instructions for printer' and listed on a separate attached sheet.

Author and title: Redhead, Physics for Pedestrians

Spelling (does not apply necessarily to quoted matter): ise/ize endings
connection/~~connexion~~; judgement/~~judgment~~; acknowledgement/~~acknowledgment~~;
focused/focussed; artefact/artifact; disc/disk; formulae/formulas;
appendixes/appendices; premise/premiss

Accents (optional): role/rôle, regime/régime

Abbreviations: usually, no points after contractions (Mr, Dr, St, Jr, and UK, EEC) - but note any different usage here.

Notes on unusual spellings, hyphenation, capitalisation, italics etc. on attached sheet

Foreign languages: (NB for French, no accents on capitals; ligature for oe and ae): e.g.
state author's system of romanisation for books with Russian/Chinese:

Possessives (give examples):

Inverted commas: single used except for displayed extracts (which have none) and quotations within quotations (which have double); punctuation follows closing inverted comma, except exclamation mark and question mark belonging to the quotation, or a full stop if the quotation is or ends with a grammatically complete sentence beginning with a capital.

Dates: 1 May 1988 (no comma); the nineteenth century; nineteenth-century (adj.); the forties; the 1760s

Cross references to specific features (e.g. 'see table 1'; 'as in ch. 4'): N/A

Numbers: elision style is 340-9, 315-19
spelt out up to 10/100 (with usual exceptions, e.g. 70 percent, £50, 2 million)
thousands: 1,200 and 12,000 (comma optional in technical books)

Bibliographical references (give example of note & bib. refs. for (1) journal article; (2) chapter in an edited book; (3) book with vol. numbers):

(1)

(2)

(3)

caps: book titles: max/min caps names of journals: max caps
journal articles and chapter titles: min/max caps
article and chapter titles with/without inverted commas

Subeditor's name: HSL Date: 8/9/88

F|C

MICHAEL REDHEAD

PROFESSOR OF HISTORY AND PHILOSOPHY OF SCIENCE
IN THE UNIVERSITY OF CAMBRIDGE

Physics for Pedestrians

AN INAUGURAL LECTURE

The right of the University of Cambridge to print and sell all manner of books was granted by Henry VIII in 1534. The University has printed and published continuously since 1584.

CAMBRIDGE UNIVERSITY PRESS

CAMBRIDGE
NEW YORK NEW ROCHELLE
MELBOURNE SYDNEY

Physics for Pedestrians

When I first studied physics at University College London everything seemed to go at a frenetic pace. We were kept so busy calculating answers to rather contrived problems in mechanics, thermodynamics, optics, electromagnetism and so on, that there seemed too little time to reflect on the general framework of what we doing, to examine the fundamental concepts of space, time, motion, matter and force that seemed to be taken so much for granted on the first pages of the textbooks. Later on when we studied relativity and quantum theory I believed things were going to be different. Now we would really have to stop and think. But again I was disappointed. Everything that interested me was swept away under a broad gloss of operationalism and positivism. Quantum mechanics in particular was presented as a black-box theory. Data were fed in representing 'experimental conditions', the handle was cranked and out came

numbers to identify with the numerical results of the experiments. What did it all mean and how did it promote understanding of the physical world? What I needed was time to stop and stare, not the bustling physics of people in a hurry, but physics for pedestrians.

It was some years later that I discovered that there *were* people interested in these very broad foundational questions in the same way I was myself, but they operated in philosophy departments rather than physics departments. They were discussing the foundations of physics, but seemed to me to be handicapped by relative lack of technical knowledge of the very theories whose foundations they were investigating. I felt that a short incursion among the philosophers would rapidly clear up the puzzles they were setting for themselves. From my very first meeting with these strange people, the philosophers, I realized it was not going to be like that at all. Far from being woolly headed or ignorant, they struck me as very clever people tackling very difficult problems. I retired chastened and much ashamed of my initial brashness. I decided I must start again from scratch, learning the technical tools of the philosophers, so that I could talk their language, and return in a much humbler frame of mind, to tackle foundational problems from a viewpoint informed by technical physics on the one hand and technical philosophy on the other.

Of course I am exaggerating. As I have now come to appreciate there are quite a number of philosophers who know a lot of physics, and a number of physicists

who would be happier in philosophy departments. Philosophy of physics is now, I would submit, a recognized discipline with practitioners spread around in this country, in Europe, in Australasia and across the Atlantic. It needs different skills from physics – like the musicologist who does not have to write symphonies or play the violin himself. It is, if you will, a second-order activity reflecting on the nature of physics. It is concerned with examining the underlying principles, concepts and ultimate presuppositions of that discipline.

Modern physics raises several broad types of philosophical problem. Firstly there are questions of the general methodology of science. This is concerned, for example, with the appraisal of theories. By what criteria should we appraise a theory as good, bad or indifferent? Is empirical adequacy the major or indeed the only criterion? Some theories are described pejoratively as *ad hoc*, what exactly does that mean? A colleague of mine, for example, recently wrote a paper with the title '*Ad hoc* is not a four letter word'![1] Then there is the matter of heuristics. How do theories develop and change? What are the correspondence relations between new and old theories? What is the role of general metaconstraints such as symmetry principles? What is the connection between models and theories? And so on. We can look at current physics in the light of these discussions and ask is it practised in a significantly different way from classical physics? Next there are ethical and aesthetic questions. What do we mean by saying that a theory is

literally true

elegant or beautiful? Should science be pursued for its own sake or in virtue of the practical advantages it confers in the form of television sets, washing machines and atomic bombs? Well, are atomic bombs of practical benefit? Should scientists work on military projects at all? And so on. Having decided what the aims of science are, we can look at its social organization and discuss whether this serves best to attain those aims. Finally there are metaphysical questions; what does physics teach us, if anything, about the ultimate nature of reality? colon

Today I am going to concentrate on this last topic, the metaphysical questions, but before coming to that I want to say something, by way of introduction, about general philosophy of science.

colon I will start with a bald (and controversial) statement; science is concerned with the nature of what is usually referred to as the 'external world'. Of course in one sense we as thinking beings belong to the external world – we are certainly not external to *other* thinking beings. But science is not concerned with our private *inner* world of thoughts, dreams, hopes, etc. *per se*. Another way of putting this is that science is concerned with *objective* reality as contrasted with our *subjective* experience of what reality.

What are the presuppositions behind this simple picture of science? Let me list a few: (1) There exits a world of physical entities. (2) Statements about them can be known to be true, or perhaps probably true, through sense experience. (3) The entities exist inde-

pendently of perception. (4) The entities are the (ultimate) cause of the sense-impressions.

But what is the status of these presuppositions? How do we come to know anything about the external world? Well, there are various sources of knowledge that may be cited including authority, intuition, revelation, faith, reason and experience. But in science two answers have traditionally been given. Firstly rationalism: some knowledge about reality can be obtained *a priori* in advance of and independently of any sense experience by pure thought (some combination of reason~~s~~ and intuition). Simple statements of arithmetic such as two plus two equals four might be thought of in this way. Secondly empiricism: all knowledge is derived from sense experience (two plus two equals four is only known from our experience of counting with apples, marbles, etc.).

Which path do you think should be followed by scientists? The answer is not entirely clear. Take empiricism for example. For many philosophers ~~to~~ the senses do not put us directly in touch with reality – far from it. We are imprisoned by our senses, they are an impenetrable wall *between* us and the external world. For example, how do we know a table is anything like our visual impression of it? To say X is *like* Y actually are before we can decide if they resemble one another. If the only route to external objects is via our sense experience how can we *ever* establish that external objects resemble their appearances? If this is true of macroscopic objects like tables, how much more

we must know how X and Y

tenuous is empirical access to micro-entities like electrons. So empiricism slides very naturally into scepticism, we know nothing about an external world, all that we know is just the *internal* world of thoughts, images nad so on, but scyience does not *deal* with that, so where does science come in? This pulls us in the direction of quite another view of science, that it *is* concerned with regularities in our sense experience. That is to follow the siren call of idealism, phenomenonalism, sensationalism.

Now let us take rationalism: surely we cannot find out anything factual about the world if we do not even look!

One way of resolving this state of affairs is what is known as *conjectural realism*. We sit in our armchairs and conjecture how the world is. We do not claim we are necessarily right, but now we subject our *conjectures* to a regime of *empirical* tests. Does the conjecture about the external world serve to explain (i.e. account for) our sensory experiences? If it does not then we can throw out the conjecture. If it does then we can continue to entertain the conjecture.

This all looks a bit pedantic when applied to tables and chairs. If you really appreciate the point about the existence of tables and chairs being a *conjecture* you are more than half-way to being a philosopher! When we come to atoms, electrons, quarks and so on, the conjectural status of these entities definately looks more appealing. After all science has been proved wrong in the past – phlogiston, the mechanical aether and so on have simply disappeared from the scientific

vocabulary. So do we really have any reason for supposing that our current high-level theories will not one day be superseded? The message here is that science does not give us certainty about the external world (even that there is an external world), we had better just be honest and admit that we cannot get that, but we can do better than completely uncontrolled speculation. Our conjectures about the world may be refuted by experiment, and that indeed is the real function of experiment, not to verify our theories, prove that they are true – that cannot be done – but to weed out inadequate conjectures. Theoretical science on this account progresses through a process of Darwinian evolution: the survival of the fittest.

This view of science is associated with the name of Sir Karl Popper, whose book *Logik der Forschung* was first published in 1934. Popper is an Honorary Graduate of Cambridge University. He is also, more humbly, Honorary Research Fellow in my old Department in London, and has deeply influenced my own thinking, so I thought it ~~was~~ appropriate to give some brief flavour of his views on this occasion.

Popper's emphasis on the refutability or falsifiability of theories as distinct from their confirmation and verification leads to a significant *demarcation criterion* between science and pseudo-science. There is no virtue in a theory which explains anything and everything. For example, Freudian psychology and Marxian socioeconomic historicism were castigated by Popper as pseudo-sciences.

The idea that scientists should spend their lives trying to *refute* their theories seems paradoxical at first sight but actually came as a relief in some cases. Sir John Eccles tells the story that he first heard Popper explain his ideas ~~to~~ in a lecture in New Zealand. At the time he was feeling very depressed because a theory he had proposed had just been refuted. He was delighted to learn from Popper that this was the ultimate aim and object of science anyway.

Although Popper believes that theories are refutable, he qualifies this by emphasizing that all experiments are themselves theory-laden. Even the existence of pointers to yield pointer-readings is a rather low-level conjecture. So the refutation of a high-level theory comes out for Popper as a conflict, not directly with experience, but with other low-level theories. The *decision* to accept these low-level theories is an essential part of scientific methodology, as is the decision not to immunize the high-level theories from refutation by *ad hoc* conventionalist strategems.

Popper does not see science progressing by an accumulation of facts, what Popper calls the bucket theory. As Popper once remarked: 'Even if you go on to the end of your lives, notebook in hand, writing down everything you observe, and if you finally bequeath this important notebook to the Royal Society... it will end up on a rubbish heap.'[1] Science starts with theories (Popper sometimes calls them searchlights) and these lead to *problems* , observations that do not fit the theories. The essential point is that problems are only problematic in the light of theories.

The fact that stones fall to the ground is only a problem in the light of a theory which says that in their natural state stones shoudl not fall to the ground. Problems lead to new theories which lead to new problems and so on *ad infinitum*.

But if none of the theories are every judged to be true, or even probably true, what objectively is being achieved? In order to answer this question Popper introduced in the 1960s a very controversial notion of *verisimiltude*, or nearness to the truth. Even if theories were not true perhaps they were increasing all the time in nearness to the truth.

As an example of the difficulties associated with this notion,[3] consider two astronomical theories T and T' both of which predict the number of planets in the solar system, P, and the number of days in the week, D (for the sake of the argument we suppose the week to be defined as the interval between successive phases of the moon.)

Consider the following table:

	P	D	$P+D$
Truth	9	7	16
T	11	5	16
T'	9	5	14

So on the basis of P and D, simply by counting the number of true predictions and subtracting the number of false predictions, we can conclude that the verisimilitude of T' is greater than the verisimilitude of

T. But now consider also P + D. *T* gets it right at 16, but *T*′ gets it wrong at 14. So if we include the prediction of P + D as well, we get that *T* and *T*′ have the same verisimilitude. But are astronomical theories really about P + D at all? This is the sort of problem that arises when one attempts any logical analysis of the comparative verisimilitude of theories.

I have concentrated so far on Popper's views about the nature of science because, in spite of technical difficulties as such as the verisimilitude problem, I think it is one of the most interesting accounts to have emerged during the last fifty years.

It is perhaps fair to say that Popper's views are more suited to the aims of pure science in its search for deep, unifying, universal laws that explain in a simple and coherent way the amazing and apparently disconnected variety that presents itself at the surface level of immediate experience, than in the looked-for justification of the *reliability* of the regularities used in applied science and technology. The standard view here is that the latter are grounded in the former, and that if we have no warrant to believe in the truth of the former, then we have no warrant to believe *qua* scientist, that the train from London to Cambridge will run tomorrow (perhaps a bad example) or that bread nourishes. My own view here is that applied science is not concerned with truth universalized over all conditions, but with limited extrapolations to the next instance for example. For this purpose Popperian strictures on non-zero rational degrees of belief may not be appropriate. This move would also justify us in treating the

refutation of a theory in particular area of application a
as a repeatable effect, which is often regarded as an inconsistent feature of the Popperian approach. But such revisionism of the pure Popperian line would take a deal more argument than I have time for here.

But there are other views that are current about science. The most prominent of these is that science is not basically a rational enterprise at all, our theories are just products of our social and cultural environment, they have nothing to do with Truth, but at best are just convenient ways of organizing our sense experiences. This attitude is really antithetical to science and scientific method which are seen as no better than astrology or witchcraft. In fact the most vocal of these anti-scientists is Paul Feyerabend, who has made exactly these claims in books such as *Against Method* and *Science in a Free Society*. The challenge of philosophy of science, as I see it, is to respond to the anti-science movement with arguments which demonstrate science as a fallible but essentially rational activity, an enterprise worthy of the *interest* and *support* of rational human beings. To quote again from Popper: 'It is not his *possession* of knowledge, of irrefutable truth, that makes the man of science, but his persistent and recklessly critical *quest* for truth.'[4]

Let us now return to the question, what can modern physics tell us (in a suitably conjectural way) about the ultimate nature of reality?

I described this as a metaphysical question. The term metaphysics is notoriously hard to pin down in philosophy. It is concerned with the most general and

pervasive features of reality, but features which are often regarded, even by definition, as beyond empirical access. We shall come to some examples in a moment, but at first glance it may seem hard to understand how an empirically based science like physics can be brought to bear on such issues. However, I hope to persuade you that this is indeed the case. But this account of metaphysics is, I believe, too restrictive, and later on in this ~~talk~~ I will adopt a more relaxed definition, which concentrates on the scope and generality of the claims being made about reality, rather than their lack of empirical testability.

Let us take a theory like quantum mechanics. There is a mathematical formalism, but to be a physical theory there must be some rules, correlating mathematical elements, typically numbers, with the results of doing experiments. In quantum mechanics, for example, we talk a lot about self-adjoint operators, but when we come to interpret the formalism as a physical theory we are interested in a special mathematical property of such operators, viz their spectrum, which consists~~s~~ of numbers directly related to the results of possible observations. So is theoretical physics just a black box in the way I mentioned in my opening remarks? To repeat: we feed some numbers in at one end, which tell us what sort of operations have been performed on a system in preparing its state, we crank the handle and out come other numbers related to the results of possible experiments we could perform on the system.

Now many philosophers and perhaps some physicists find this account of theories unsatisfactory. They want to go beyond this view, to get out the screwdriver, lever off the lid of the black box and look inside, or expressed more formally to provide an interpretation of physics in a different sense from that just employed (i.e. rules correlating elements of the mathematics with physical quantities). This new ~~series~~ sense of interpretation is to give an account of the nature of reality and of our epistemol~~i~~ogical relation to it which serves to explain how these empirical regularities come about.

Let me return to a simple example we have already discussed. I see a table in front of me. I turn my head and then look again – and see the table. The simplest conjecture that will explain this regularity in my sense experience is that there actually exists a substantial physical object, namely the table, which continues to exist when neither I nor indeed anybody else is looking, combined with claims about how physical objects cause or produce sense experiences. Notice that the existence of physical objects *per se* is an entirely metaphysical statement, in the first sense we described. It can neither be proved nor disproved empirically. It is only when conjoined with other statements that it has testable experiential consequences. But we would never be led to the testable theory without starting from the metaphysical idea of an external physical world populated by substantial physical objects such as tables and chairs.

Before coming to modern physics I will give a brief historical discussion about another sort of metaphysical question. Suppose you take a lump of matter, say again this table, and try to chop it up into very small pieces. How long could you go on dividing it up? This question intrigued the ancient Greeks and they traditionally gave two answers:

(1) Matter is infinitely divisible. This was the view of Aristotle for example.
(2) There is a stage beyond which you cannot go on dividing. You have reached the ultimate atoms. This was the view of Leucippus, Democritus and Epicurus to mention some of the most famous of the ancient atomists.

Notice that the questions cannot be settled empirically, even in conjunction with statements linking the experiment to sense experience. We cannot prove atomism at any putative stage. Perhaps we have not been knocking the atoms hard enough to break them up. But also we cannot disprove it. If we have not reached the atoms yet perhaps we shall meet them further down the sequence of potentially infinite division.

Atomism, for the Greeks, was a metaphysical doctrine designed to account for the possibility of change in the universe – famously denied by Parmenides for example. The atoms do not change themselves, but they move around in the void, changing their configurations, and this is the ultimate explanation of all the

changes we see around us in our macroscopic observable world.

This is a very importatn point. To describe change we must presume something that is not changing. To say that X changes from condition P to condition Q there must be something unchanging about X to enable us to identify it as X throughout the ~~cvhnage~~. This idea is very important in modern physics under the guise of invariance or symmetry.

change

During the Middle Ages views largely prevailed, at any rate in Western culture. But atomism was revived in the seventeenth century by Pierre Gassendi and others under the general rubric of Corpuscularianism. Many of the great seventeenth-century scientists such as Boyle and Newton believed, with varying degrees of conviction, that matter was ultimately corpuscular.

Aristotelian

However atomism did not become a scientific theory, in the sense of producing surprising empirical predictions, until the nineteenth century – firstly in chemistry by Dalton and later in the general kinetic theory of matter which arose in the second half of the nineteenth century. This latter theory said that in reality matter consisted of the chemical atoms, sometimes aggregated in larger groupings called molecules, which were in constant random motion, which we observe as heat.

Notice here a very important point. Kinetic theory does not depend on the atoms being totally indivisible, only that collisions at the ordinary temperatures under discussion should not split them up. This pragmatic

sense of atomism, quite different from the metaphysical Greek sense, yields an empirically testable scientific theory. But we can also obtain a testable theory by substituting metaphysical atomism with the assertion that the *chemical* atoms *are* the 'ultimate' atoms. This is a stronger theory than pragmatic atomism since it s/ implied it but is not implied by it. As we shall see it is refutable, and indeed refuted, by 'splitting the chemical atom' which would not be the case for pragmatic atomism. Note also that this chemical atomism implies metaphysical atomism. This point should be stressed. Perfectly 'respectable' scientific theories can logically imply untestable metaphysical statements.

Coming to the twentieth century then theoretical Comma physics has given up the idea that the chemical atoms are indivisible. In fact they also have structure. Physically an atom consists of a nucleus carrying a positive electric charge surrounded by very small negatively charged particles called electrons, going round the nucleus rather like planets round the sun. In a hydrogen atom, for example, the radius of the electron orbit is about 10^{-8} cm. So we can split the atom by splitting off electrons. But that is not all. It also turns out that the nucleus has structure. It is made up of still smaller particles – the protons and neutrons.

In the last fifteen years it has been found that the protons and the neutrons also possess structure. They are made up of still smaller constitutents known as *quarks*. There are several varieties of these quarks, which together with the electron and related particles collectively referred to as *leptons*, appear at the pres-

ent time to represent the *ultimate* constitution of matter.

So we are just back to indivisible particles and the void where it all started from? This table is really mostly empty space with myriads of very small *ultimate* constituent particles aggregated in various ways not unlike the stars and galaxies which fill the sky. The question as posed about *ultimat* constituents would be, as we have seen, a typically metaphysical question, not capable of being settled empirically, and in this sense entirely speculative. The metaphysical problem the Greeks confronted was quite independent of whether any given pragmatic atoms were the ultimate atoms. Nevertheless it should be noted that metaphysical atomism is a strong heuristic guide in formulating testable atomic theories at all.

Let us now probe a bit deeper into modern physics. Let us concentrate on the electron as a typical example of an *elementary particle*. It's mass is only 10^{-27} gramme. Until very recently physicists thought it might have no size, but be literally a mathematical point (I am not today going to discuss the stop-press physics of string). It carries a charge of about 10^{-19} coulomb. But it turns out that the laws governing the motion of electrons are quite different from those governing the motion of large-scale objects such as tables or chairs. The latter are governed by laws discovered by Newton at the end of the seventeenth century, but in the 1920s it was found that electrons obey quite different mechanical laws – known as quantum mechanics.

Quantum mechanics says, in brief, that electrons do not behave just like particles, but somewhat like waves. But they are not quite like waves either – in some respects they are like classical Newtonian particles. They exhibit the famous wave-particle *duality*. Understanding this dual nature of the electron (wave plus particle aspect) is a major metaphysical problem which I shall not discuss in detail on this occasion. The point I want to make here is that if electrons are like waves, they are in some spread through space in a continuous fashion. Even a single electron is in some sense everywhere at once. When I said the hydrogen atom had a size of 10^{-8}cm, I should have said the electron waves were mainly concentrated in a region of this size, although theoretically the amplitude of the waves never falls absoutely to zero. If an electron *considered as a particle* is a mathematical point can I localize it with absolute precision? Well no, when I said it was a point that was a highly theoretical statement. If you try experimentally to squeeze an electron wave into a very small space, to localize it precisely, an extraordinary thing happens. When you get to about 10^{-11} cm a second electron pops up out of nowhere – well, out of the vacuum. Actually, to conserve charge you have to create negatively and positively charged *pairs*, but that is an inessential complication for my purposes. The more you squeeze, the more electrons appear, so you cannot localize a *single* electron to better than 10^{-11} cm. I said these new particles came out of the vacuum. But there is an ever more surprising thing. The vacuum is full of

latent or virtual particles as they are called. The vacuum is not *nothing* but is seething with activity. Speaking metaphorically and picturesquely, latent particles try to achieve an actual existence and then fall back into oblivion!

This problem about matter being created (or annihilated) is not a new one. It has after all a long theological ancestry! The idea of atoms was that they did not themselves change (except in location). If they do not change ever they must exist for ever. If we want to have atoms that can come and go should we not think of matter as fundamentally a wave-like phenomenon? After all ripples come and go on the surface of a pond. This view and the natural way in which it can accommodate creation and annihilation is a major motivation behind quantum field theory. A word of warning: do not confuse quantum field theory with the waves in wave-particle duality. There is a connection, but quantum fields have a particle aspect to them – they also exhibit a form of wave-particle duality!

But because quantum field theory is rather technical let me discuss a related metaphysical problem as it presents itself in classical physics. How does a particle go from A to B? Well, does it just move over from A to B? Thus:

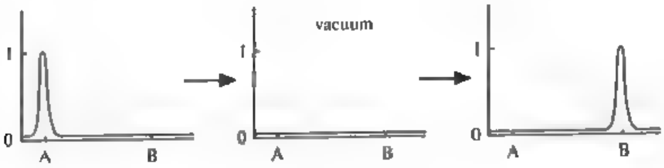
But we could also describe the situation by saying that a certain property of impenetrability was transferred

from A to B. (It is fitting that I follow here Newton, the tercentenary of whose magnum opus we have been celebrating at Cambridge this year, and who introduced just this idea in his early anti-Cartesian work entitled in translation 'On the gravity and equilibrium of fluids'.[5] We could introduce a simple dichotomic field with two possible values for every point of space. The value 0 corresponds to no impenetrability, i.e., no particle present, the value 1 to the presence of impenetrability, i.e. a particle *is* present. So the state of the field at time t_1 when a particle is at location A is like this:

The state of the field at time t_2 when the particle is at location B is like this:

So how does the particle go from A to B? Well, the spike or blip in the field propagates from A to B rather like a wave travelling down a string. But why should we not describe the motion as a two-stage process? The spike at A is annihilated at time t_1 leaving us with

the vacuum field, and then the spike at B is created out of the vacuum at the later time t_2. Thus:



But this theory is empirically false! Because if we look at a time between t_1 and t_2 there is a blip somewhere between A and B, so the vacuum prediction is wrong. But let us suppose the interval from t_1 and t_2 is divided up into a very large sequence of 'time atoms' and we claim that motion consists in the 'particle' being annihilated and recreated across successive time atoms. Then, whenever we look between the time atoms the blip is there, but we cannot look during a time atom~~s~~, whatever that would mean, so we can never not see the blip. This view of motion was actually adopted by the Mutakallemim in ancient Islamic philosophy and has obvious affinities with ideas of creation and annihilation in modern quantum field theory.

We have a typical situation of *underdetermination*. The field description and the substantial particle description of the motion are empirically equivalent – the particle gets from A to B, and is always observed when looked for, but because field and particle descriptions are empirically equivalent does not mean they are heuristically equivalent when one leaves the arena of classical physics and tries to produce physical

theories to account for the transient nature of many of the elementary particles. As Popper has stressed, metaphysical views about the ultimate nature of reality may be rationally assessed, not in terms of their empirical testability which they may not have, but in terms of how well they deal with metaphysical problems such as the ultimate account they give of change, creation and so on, but more especially in terms ~~in~~ their fertility in guiding the development of new physical theories which *are testable* and may actually survive severe testing.

In conclusion let me return to a puzzle about quantum mechanics. I said electrons, protons, etc., were in a sense 'spread' everywhere. But if tables and chairs are made up of these particles should they not then be spread out? Should not this table in front of me be 'spread' partly to the other side of the room. In fact if you take quantum mechanics quite seriously there are ways in which this can actually happen. Another version of this problem is known as the Schrödinger cat paradox. Schrödinger invented an experiment whereby a cat could be predicted to be 'spread' simultaneously between a state of being alive and being dead. This type of prediction is generally regarded as a flaw in the theory! What would the cat itself think was going on?! Some authors see in this puzzle, and other related problems of so-called entangled systems, a denial of the possibility of a mind-independent reality of the sort proclaimed at the beginning of this talk. I do not myself believe that quantum mechanics cannot be given a realist con-

strual, although at the expense of an admittedly mysterious and still not properly understood holistic involvement of component parts of a composite system. That is not to say I am claiming to prove realism or to disprove for example the Copenhagen complementarity interpretation. I advocate keeping metaphysical options open to see which leads to the most progressive physics.

I mention these problems in order to stress that microphysics present many conceptual difficulties that physicists themselves tend to brush under the carpet. Physics is not so neat and tidy and unproblematic as the amn on the Clapham omnibus might suppose.

To sum up then, conceptual problems in physics may highlight points at which the theory is in need of further foundational investigation. But the main theme here has been the creative heuristic role in physics of very general metaphysical claims about the world, which are not themselves empirically testable, and hence, in some over-restrictive sense, might be thought unscientific.[6]

The importance of metaphysics in guiding the construction of physical theories is particularly in evidence in revolutionary periods, when one is looking for new days of doing physics. At this stage metaphysics may well drive physics. In periods of what Kuhn calls normal science, it can be the other way around. Current physics if empirically supported may be regarded as lending rational support to the metaphysics which led to the new theory. Rationality here does not equate with certifiable truth, but with a

balance of argument on greed criteria applied to the current state of play leading to acceptance, which is to be sharply distinguished from belief. In this sense we may well talk of *experimental metaphysics*.

Indeed at all stages in the development of physics there should be a two-way interaction between physics and philosophy (here identified with metaphyscs). Even if physicists, imbued with a positivistic or instrumentalist ideology, arrive at new theories just by guessing at equations, the philosopher of physics may look at such bits of mathematical formalism and seek for an interpretation in the sense we have described, an embedding of the empirical regularities in a general metaphysical framework. The result may not be unique, as in the quantum mechanics case, but at least some possibilities can be definely ruled out. Even in the case of attempted interpretations, such as local realism in quantum mechanics, which turn out not to fit the formalism, this may suggest possible weak points in hitherto untested areas of empirical adequacy. This was the case in the recent Aspect experiment. Here was a crucial experiment, modulo the usual assumptions about the way the apparatus works, to test assumptions of locality and realism in the interpretation of quantum mechanics. Whichever way the result went, the experiment was of decisive importance. Either it would refute a combination of very general interpretative principles whose very generality indeed invited the status of metaphysics in the second, more relaxed sense we adumbrated earlier on, so we have here a more immediate sense of doing

experimental metaphysics which, on this second account of metaphysics, no longer threatens as a contradiction in terms. Or the experiment would refute the empirical adequacy of the theory. As we now know the empirical adequacy survived, but in the end, if we accept the so-called pessimistic induction about the eventual breakdown of predictive success of any theory in physics, based on a long view of the history of the discipline, quantum mechanics *will* be found deficient, and then the philosopher of physics may play a role, as we have seen, in offering the physicists possible conceptual frameworks within which to develop the new physics. The moral is that sometimes philosophy nudges physics, and so physicists had better learn some philosophy, while sometimes physics nudges philosophy so philosophers had beter attend to physics.

Let me finish then by contrasting the usual textbook of theoretical physics, which starts on page 1 with some uncritically presented presuppositions and then proceeds to develop applications through pages 2, 3, etc., with the textbook for pedestrian physics, where I would advocate a new set of pages numbered minus 1, minus 2, etc., in which the concepts and assumptions introduced on page 1 are subjected to increasingly searching critical examination. No doubt the book would extend ultimately to infinity in both the positive and negative directions. Here at Cambridge I propose to continue in my attempt to write just a few more of the negative pages.

Acknowledgement. I would like to express my gratitude to Karl Popper, Heinz Post and John Watkins, whose ideas have shaped and influenced all of my work in philosophy of science.

Notes

1. Allan Franklin, unpublished manuscript.
2. *Conjectures and Refutations*, London: Routledge and Kegan Paul, 4th edn, 1972, p. 128.
3. Cf. David Miller 'The accuracy of predictions', *Synthese*, 30, 1975, p. 159.
4. *The Logic of Scientific Discovery*, London: Hutchison and Co., 1959, p. 281.
5. See A. R. Hall and M. B. Hall (eds.), *Unpublished Scientific Papers of Isaac Newton*, Cambridge University Press, 1962, p. 89.
6. Cf. K. R. Popper, *Quantum Theory and the Schism in Physics*, London: Hutchison and Co., 1982, pp. 159ff.; J. W. N. Watkins, 'Confirmable and influential metaphysics', *Mind*, 67, 1958, p. 344; J. W. N. Watkins, 'Metaphysics and the advancement of science', *The British Journal for the Philosophy of Science*, 26, 1978, p. 91.

This lecture is dedicated to the memory of my mother,
who would have been pleased.

B/C.

Published by the Press Syndicate of the University of Cambridge
The Pitt Building, Trumpington Street, Cambridge CB2 1RP
32 East 57th Street, New York, NY 10022, USA
10 Stamford Road, Oakleigh, Melbourne 3166, Australia

© Cambridge University Press 1988

First published 1988

Printed in Great Britain by
University Printing Services, Cambridge

ISBN 0 521 37800 1